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Research Article

Growth Scale Optimization of Discrete Innovation Population Systems with Multichoice Goal Programming

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How are limited resources efficiently allocated among different innovation populations? The performances of different innovation populations are quite different with either synergy or competition between them. If the innovation population is kept under an appropriate scale, full use can be made of the allocated resources. The maximization of the development and performance for a certain scale of innovation population is a typical multichoice development problem. Therefore, the scale optimization of the innovation population should be analyzed. According to the population dynamics, a resource constraint model for the growth of innovation population is developed, and the growth of innovation population under resource constraints is in equilibrium accordingly. With the help of a multichoice goal programming model, the scale optimization of innovation population performance can be obtained. The results of the resource constraint model and multichoice goal programming model are used to determine the optimal scale of the innovation population. From the panel data of the innovation population in Jiangsu Province from 2000 to 2017, we have found that R&D investment was the main innovation resource variable and that patent number was the main innovation output variable. Based on these data, the scale optimization of the innovation population under resource constraints can be calculated. The results of the study show that, in the observation period, the enterprise innovation population is often in the appropriate scale state. The scale development of enterprise innovation population is often more suitable for innovation ecosystem than that of scientific research institutions. According to these results, the government can provide appropriate guiding policies and incentives for different innovation populations. The innovative population can adjust its own development strategy and plan in time accordingly.

1. Introduction

In real economic activities, the essence of enterprises' innovation behavior is to seek differences. The competitive advantages and the improvement of production efficiency brought by enterprises through innovation are the roots of realizing economic growth and sustainable change. Since endogenous growth theory regards technological progress as the source of economic growth, the research on technological innovation and economic growth is currently a hot topic in academic circles. However, the objective hypothesis of "innovation homogeneity" is always considered a defect of endogenous growth theory [1]. In fact, the differences in production technology, geographical environment, corporate culture, and factor accumulation in real life often led to the obvious heterogeneity of different enterprises.

Innovation activity is a systematic engineering issue. It is difficult for a single organization to have all the resources they need for innovation. The construction of an innovation ecosystem, an open, nonlinear, multilevel, and complex system with dynamic evolution, is an important basis for innovation, entrepreneurship, public management, and industrial development in an era of change. The basic elements of the innovation ecosystem are enterprises, universities, and scientific research institutions. Innovation species are the collections of the innovation elements, and the collection of innovation species forms an IP. A variety of IPs are linked together to form various communities in the innovation ecosystem. The symbiosis and interaction of IPs contribute to the evolution of the innovation ecosystem. The heterogeneity among various IPs is reflected in the innovation resource input [2], innovation output, and innovation interaction mechanism [3]. How to optimally allocate resources is the basic matter of theoretical research and social practice in the fields of economics [4] and management [5]. How do resource constraints affect relationships between IPs? What is the appropriate interaction mechanism between IPs? These are the main questions in the study that should be answered while constructing an appropriate enterprise innovation ecosystem to effectively improve innovation behavior and competitiveness. If its scale is too small, the IP cannot make full use of the relevant resources in the innovation ecosystem; in this case, innovation resources will be left idle in the innovation ecosystem. If the scale is too large, it will cause the competition of IP for resources in the innovation ecosystem and increase the transaction cost of resource allocation for IP [6].

An appropriate scale and development level of the innovation ecosystem can support the development of IP efficiently. What is the suitable range for the development scale of IP? When the population is on an appropriate scale, the IP will be in a collaborative state, which improves the performance of the IP. In this case, the resources in the innovation ecosystem can be fully utilized, and the innovation performances can be maximized [7]. The impact of industrial clusters on enterprise innovation is considered to be positive in some studies [8, 9]. However, some literature studies found that the cluster has a negative effect on enterprise innovation [10, 11]. This study is a development and expansion of organizational ecology. The population scale in a region determines the population density. Existing studies generally use the population density index to analyze the relationship between population scale and innovation performance. Given these two different conclusions, it is necessary to establish a new framework to analyze the relationships between an enterprise's population size and its innovation ability. Therefore, the topic of population ecology should be addressed. Hannan and Freeman [12] analyzed the enterprise problem based on the logic of population ecology, and they founded the organizational ecology field. This present study further develops and expands the population ecology framework.

It is obvious that the research of innovation ecosystem is deepening gradually and that the current research focuses on its concept, characteristics, structure, and operation mechanism. However, few studies are conducted about population dynamics or other ecological methods. The growth characteristics of an innovative ecosystem and its innovative population accord with the laws of ecology, and they need to be verified by relevant ecological theories and methods. Most studies are made from the enterprise level, using ecological models to verify the evolutionary relationship between two subpopulations. In reality, it is more common to form a technological innovation ecosystem where subpopulations are mutually influenced and interdependent. There are few quantitative studies on the relationship between innovation populations.

Population dynamics is often used to analyze the cooperative or competitive relationship between populations. The research shows that the introduction of the population dynamics model into market competition and diffusion produces better analysis results [13, 14]. The population dynamics model can be adopted to explain the dynamic competition relationship of the stock market [15], product portfolio optimization [16], the symbiotic relationship between competitors in the mobile communication market [17], and the dynamic competition and equilibrium point of TV product population [18]. Based on previous studies, this paper selects interdependent innovation groups as the research object and uses the population dynamics model to study the coordination and balance level between innovation groups in the innovation ecosystem. Different from previous studies, this study, when using the population dynamics model, is not simply based on the scale of innovation groups to explore the collaborative relationship, but based on the number of innovation groups and multiobjective research such as input-output optimization, to explore the appropriate growth scale of innovation groups.

2. Materials and Methods

Based on the ecological theory, innovation theory, and population dynamics method, this paper constructs an interaction mechanism model of innovation population. With the objective of resource constraints, population symbiosis effect, and innovation output maximization, the optimal size of the innovation population is determined by a multiobjective programming model. Considering the characteristics of the IP symbiotic system, a comprehensive evaluation method is needed to solve the above multiobjective optimization problem. From the perspective of resource constraints, this paper constructs a dynamic model of population growth in the innovation ecosystem. The suitability of population size is estimated by means of multiobjective programming. This study also constructs a theoretical model from two aspects of input constraints and output maximization, which is a theoretical innovation. Moreover, this research has practical significance, as it provides an appropriate analysis method for each innovation agent to analyze and plan the development scale of the population. The research process of this paper is shown in Figure 1.

As shown in Figure 1, this paper builds population dynamics systems to show the interactive mechanism in the innovation system and builds a multichoice goal programming (MCGP) model for scale optimization.

2.1. Innovation Population Growth Mechanism. According to the logistic model, the internal relationship model of enterprise IP (population 1) is constructed. We can get

$$g_{1(t)} = \frac{\mathrm{d}N_{1(t)}}{d_t} = \alpha_1 N_{1(t-1)}\left\{1 - \frac{N_{1(t-1)}}{K}\right\}, \tag{1}$$

where $g_{1(t)}$ indicates the population growth rate of phase t. $N_{1(t)}$ indicates the number of individuals of the population in phase t. $N_{1(t)}/K$ represents the number of resources occupied by populations of phase t. Within a population of an innovation ecosystem, each unit that occupies resources is defined as $1/K$.

$$\begin{aligned}\text{Because: } dN_{1(t)} &\approx \Delta N_{1(t)} = N_{1(t)} - N_{1(t-1)}, d_t \\ &\approx \Delta t = t-(t-1) = 1, \\ \text{So: } \Delta N_{1(t)} &= \alpha_1 N_{1(t-1)} + \beta_2 N_{1(t-1)}^2.\end{aligned} \quad (2)$$

$\Delta N_{1(t)}$ is the number of individuals in a population during the Tperiod. Usually, it is defined as $\alpha_1 > 0$, indicating synergistic effects within populations. $\beta_2 = -\alpha_1/K$, usually $\beta_2 < 0$ representing the internal competition effect of the population. The coefficient of internal competition or population density is called the inhibitory factor.

$$\begin{aligned}N_{1(t)} &= \Delta N_{1(t)} + N_{1(t-1)} = (\alpha_1+1)N_{1(t-1)} + \beta_2 N_{1(t-1)}^2, \\ \text{set: } \beta_1 &= \alpha_1 + 1, \\ \text{get: } N_{1(t)} &= \left\{\beta_1 + \beta_2 N_{1(t-1)}\right\} N_{1(t-1)}.\end{aligned} \quad (3)$$

If $\left\{\beta_1 + \beta_2 N_{1(t-1)}\right\} > 1$, then $\Delta N_{1(t)} > 0$. The synergistic effect is dominant in the population. Resources within an innovative ecosystem can support an increase in the number of individuals in an IP. Thus, the growth can be sustainable.

If $\left\{\beta_1 + \beta_2 N_{1(t-1)}\right\} < 1$, then $\Delta N_{1(t)} < 0$. The competition effect is dominant in the population. It is difficult to use innovative resources to support the increase in the number of individuals in the IP. Thus, the growth is unsustainable.

Considering the influence of the environment on population, this paper studies the impact of scientific research institution IP on enterprise IP.

$$N_{1(t)} = \beta_{12} N_{2(t)}, \quad (4)$$

where $N_{2(t)}$ is the number of individuals of scientific research institutions' IP (population 2) in t period and β_{12} is the influence coefficient of population 2 on population 1.

Then, the logistic model can be modified as follows:

$$g_{1(t)} = \frac{dN_{1(t)}}{d_t} = \alpha_1 N_{1(t-1)}\left\{1 - \frac{N_{1(t-1)}}{K} + \frac{\beta_{12}N_{2(t-1)}}{K}\right\}. \quad (5)$$

Equation (4) is substituted by equation (5) to obtain

$$\Delta N1(t)' = \gamma_1 N_{2(t-1)} + \gamma_2 N_{2(t-1)}^2. \quad (6)$$

Among them, $\gamma_1 = \alpha_1\beta_{12}$, $\gamma_2 = 2\alpha_1\beta_{12}^2/K$; we can get

$$\Delta N_{1(t)} = \left\{\gamma_1 + \gamma_2 N_{2(t-1)}\right\} N_{2(t-1)}. \quad (7)$$

We can judge the relationship between population 1 and population 2 according to the value of γ_1 and γ_2.

If $\left\{\gamma_1 + \gamma_2 N_{2(t-1)}\right\} > 0$, then $\Delta N_{1(t)} > 0$. The population is dominated by the synergy effect, and innovation resources can support the increase of the individual number of IPs, and the growth can be maintained. If $\left\{\gamma_1 + \gamma_2 N_{2(t-1)}\right\} < 0$, then $\Delta N_{1(t)} < 0$. The population is dominated by the competition effect, and it is difficult to use innovation resources to support the increase of the individual number of IPs, and the growth is difficult to maintain.

Considering the influence of the government and various service agencies (such as law firms, accounting firms, consulting companies, advertising companies, and human resources service agencies), formula (4) is further expanded to the following formula:

$$N_{1(t)} = \beta_{12} N_{2(t)} + \alpha_{zf} N_{1(t-1)} + \alpha_{fw} N_{1(t-1)}. \quad (8)$$

Among them, α_{zf} is the incentive coefficient of the government to the IP, and $\alpha_{zf} = j - s$. j is the preferential policy of the government used to encourage innovation. s is the tax for the impact of various service institutions on the IP.

There is also competition or synergy within the research population. Therefore,

$$g_{2(t)} = \frac{dN_{2(t)}}{d_t} = \alpha_2 N_{2(t-1)}\left\{1 - \frac{N_{2(t-1)}}{K}\right\}, \quad (9)$$

where $g_{2(t)}$ represents the population growth rate of the T-stage and $N_{2(t)}$ is the number of individuals in the T-stage. $N_{2(t)}/K$ indicates the number of resources occupied by the population in period T, and the resources occupied by each unit of a population in the innovation ecosystem are $1/K$.

Comprehensive consideration of population internal relationship and environmental impact can be shown as

$$\begin{aligned}N_{1(t)} &= \left(1 + g_{1(t)} + g1(t)'\right)N_{1(t-1)} + \alpha_{zf}N_{1(t-1)} + \alpha_{fw}N_{1(t-1)} \\ &= \left\{1 + \alpha_1 N_{1(t-1)}\left(1 - \frac{N_{1(t-1)}}{K}\right) + \alpha_1 N_{1(t-1)}\left(1 - \frac{N_{1(t-1)}}{K} + \frac{\beta_{12}N_{2(t-1)}}{K}\right)\right\}N_{1(t-1)} + \alpha_{zf}N_{1(t-1)} + \alpha_{fw}N_{1(t-1)}.\end{aligned} \quad (10)$$

The following formula can be obtained:

$$N_{1(t)} = (1 + \alpha_{zf} + \alpha_{fw})N_{1(t-1)} + 2\alpha_1 N_{1(t-1)}^2 - \frac{2\alpha_1}{k}N_{1(t-1)}^3 + \frac{\alpha_1\beta_{12}}{k}N_{1(t-1)}^2 N_{2(t-1)}. \quad (11)$$

Let $1 + \alpha_{zf} + \alpha_{fw} = \eta_1$,

$$\text{then: } N_{1(t)} = \eta_1 N_{1(t-1)} + 2\alpha_1 N_{1(t-1)}^2 - \frac{2\alpha_1}{k}N_{1(t-1)}^3 + \frac{\alpha_1\beta_{12}}{k}N_{1(t-1)}^2 N_{2(t-1)}, \quad (12)$$

$$\text{because: } N_{2(t)} = \left(1 + g_{2(t)}\right)N_{2(t-1)} = \left\{1 + \alpha_2 N_{2(t-1)}\left(1 - \frac{N_{2(t-1)}}{K}\right)\right\}N_{2(t-1)}, \quad (13)$$

$$\text{so: } N_{2(t)} = N_{2(t-1)} + \alpha_2 N_{2(t-1)}^2 - \frac{\alpha_2}{k}N_{2(t-1)}^3. \quad (14)$$

We can get the partial derivation of the two sides of the equal sign of equations (12) and (14)

$$\begin{cases} \dfrac{\partial N_{1(t)}}{\partial N_{1t-1}} = \eta_1 + 4\alpha_1 N_{1(t-1)} - \dfrac{6\alpha_1}{k}N_{1(t-1)}^2 + \dfrac{2\alpha_1\beta_{12}}{k}N_{1(t-1)}N_{2(t-1)}, \\ \dfrac{\partial N_{2(t)}}{\partial N_{2(t-1)}} = 1 + 2\alpha_2 N_{2(t-1)} - \dfrac{3\alpha_2}{k}N_{2(t-1)}^2. \end{cases} \quad (15)$$

The second-order partial derivative can be obtained:

$$\begin{cases} \dfrac{\partial^2 N_{1(t)}}{\partial N_{1(t-1)}^2} = 4\alpha_1 - \dfrac{12\alpha_1}{k}N_{1(t-1)} + \dfrac{2\alpha_1\beta_{12}}{k}N_{2(t-1)}, \\ \dfrac{\partial^2 N_{2(t)}}{\partial N_{2(t-1)}^2} = 2\alpha_2 - \dfrac{6\alpha_2}{k}N_{2(t-1)}. \end{cases} \quad (16)$$

When the population reaches the equilibrium state, the second derivative is zero, and the following equations can be obtained:

$$\begin{cases} 4\alpha_1 - \dfrac{12\alpha_1}{k}N_{1(t-1)} + \dfrac{2\alpha_1\beta_{12}}{k}N_{2(t-1)} = 0, \\ 2\alpha_2 - \dfrac{6\alpha_2}{k}N_{2(t-1)} = 0. \end{cases} \quad (17)$$

The only nonnegative solution can be obtained by solving the above equations; that is, the equilibrium point is $(k/3 + k\beta_{12}/18, k/3)$. This equilibrium point represents the equilibrium state of innovation resources occupied by the enterprise IP and scientific research institution IP. By dividing the value of this point by the average amount of innovation resources $(1/k)$ obtained by each unit of IP, we can get the equilibrium value of the IP scale.

2.2. Multichoice Goal Programming (MCGP). In recent years, multichoice goal programming (MCGP) has been widely used to solve many practical decision-making problems. The multichoice goal programming (MCGP) method proposed by Chang et al. [19, 20] is described as follows:

$$\begin{aligned} &\text{objective function: Min} \sum_{i=1}^{n}(d_i^+ + d_i^-) + \sum_{i=1}^{n}(e_i^+ + e_i^-), \\ &\text{constraints: } \begin{cases} f_i(x) - d_i^+ + d_i^- = g_i,\ i = 1, 2, \ldots, n, \\ x \in X = \{x_1, x_2, \ldots, x_m\}, \\ g_i - e_i^+ + e_i^- = g_{i,\max},\ i = 1, 2, \ldots, n, \\ g_{i,\min} \le g_i \le g_{i,\max},\ i = 1, 2, \ldots, n, \\ d_i^+ + d_i^-, e_i^+, e_i^- \ge 0,\ i = 1, 2, \ldots, n, \\ X \in F,\ (F \text{ is the set of feasible solutions}). \end{cases} \end{aligned} \quad (18)$$

Here, d_i^+ and d_i^- indicate, respectively, the value of the i-th goal exceeding and not reaching the expected value of the goal. $f_i(x)$ is the objective function of the i-th objective. X is the decision variable, representing m alternatives $(x_1, x_2, \ldots, x_m)$. g_i is the expected level for the i-th goal. e_i^+ and e_i^- are positive and negative deviation variables close to $|g_i - g_{i,\max}|$. $g_{i,\min}$ and $g_{i,\max}$ are the lower and upper limits of the target respectively of g_i. MCGP is a linear form of objective programming, which can be solved by some common linear programming software.

2.3. Materials. China's macroeconomic growth has entered the track of medium-speed development. The primary goal of policy reform is to create a new engine of the economy, cultivate new economic growth points, and finally accelerate industrial transformation and upgrading, and enhance the competitiveness of the real economy by relying on an innovation-driven development strategy. The economic system should not only increase R&D investment and promote investment in the strategic emerging industry but also pay attention to the quality and efficiency of innovation investment. How to make correct innovation investment decisions is very important for different IPs. In China, the government plays a very important role in the innovation ecosystem. The government can adjust the policy according to the growth state of IP under the restriction of resources and promote the development of innovation activities.

Jiangsu Province, a developed province in the east of China and an active area of innovation, is taken as an example. The population quantity equilibrium point of the regional innovation ecosystem is calculated.

Variable interpretation and data selection are as follows:

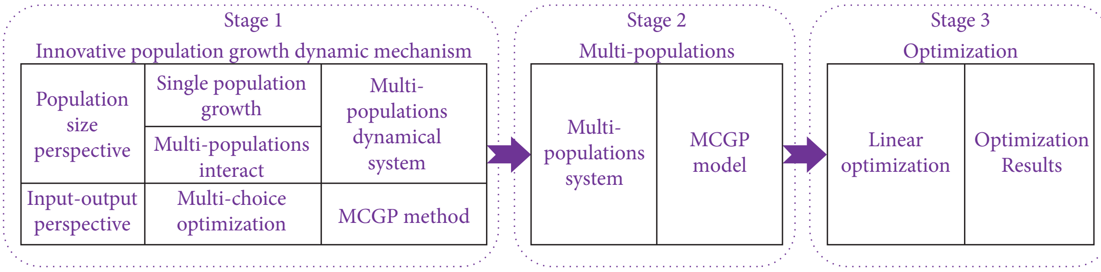

Figure 1: Innovation population-scale evaluation process.

(1) P_1: population size of innovative enterprises (number of enterprises with scientific and technological activities, unit: number)

(2) P_2: population size of scientific research institutions (number of scientific research institutions, unit: number)

(3) $E_{R\&D}$: R&D expenditure (unit: 100 million yuan)

(4) P_3: the comprehensive data of scientific research organization ($P_3 = P_1 + P_2$)

(5) $\overline{R}$: the average amount of innovation resources ($\overline{R} = 1/K$, unit: 10,000 yuan)

(6) E_1: equilibrium solution of equations for population 1 ($E_1 = k/3 + k\beta_{12}/18$, unit: 100 million yuan)

(7) E_2: equilibrium solution of equations for population 2 ($E_2 = k/3$, unit: 100 million yuan)

(8) EP_1: equilibrium value of enterprise IP size ($8 = 6/5$)

(9) EP_2: equilibrium value of scientific research institutions ($9 = 7/5$)

The calculated data and the specific data are shown in Table 1. The data in Table 1 are taken from Jiangsu Statistical Yearbook (2001–2018) and relevant calculations are carried out.

As shown in Table 1, from 2000 to 2010, the actual value of the enterprise IP scale is lower than the equilibrium value, which indicates that, in this stage, innovation resources are relatively sufficient and not fully utilized. From 2011 to 2017, the actual value of the enterprise IP scale is significantly higher than the equilibrium value, and the degree of deviation is increasing. The growth of enterprise IP is constrained by innovation resources.

For the population scale of universities and scientific research institutions, the actual value is higher than the equilibrium value from 2000 to 2003. It shows that the number of universities and scientific research institutions in this period is larger than the equilibrium value. In this period, too many scientific research institutions have occupied the resources of the Jiangsu innovation ecosystem and have squeezed the development space of enterprise IP. From 2004 to 2017, the actual value of IP size of universities and scientific research institutions is lower than the equilibrium value, indicating that, in this stage, innovation resources are relatively sufficient and not fully utilized.

2.4. Empirical Analysis. In this case, the number of authorized patents is taken as a measure of innovation output. The scale of IP suitable for Jiangsu regional innovation ecosystem calculated by Lingo 11 software is shown in Table 2. The objective solution of MCGP and the solution of the resource constraint model (equilibrium value) is used to construct the interval of population suitability (taking the maximum value as the upper limit of the interval and the minimum value as the lower limit of the interval).

Variable interpretation and data selection are as follows:

(1) MP_1: MCGP target solution for population scale of innovative enterprises

(2) MP_2: MCGP target solution for population scale of scientific research institutions

(3) IP_1: suitable interval of scale for population 1, $IP_1 = (\mathrm{MIN}\ (MP_1, EP_1), \mathrm{MAX}\ (MP_1, EP_1))$

(4) IP_2: suitable interval of scale for population 2, $IP_2 = (\mathrm{MIN}\ (MP_2, EP_2), \mathrm{MAX}\ (MP_2, EP_2))$

(5) ARP_1: judging whether the scale of population 1 is in the appropriate range (true or false)

(6) ARP2: judging whether the scale of population 2 is in the appropriate range (true or false)

As shown in Table 2, the IP of enterprises in Jiangsu Province is in a suitable range for most of the time, and its scale is appropriate. The population scale of scientific research institutions is out of the appropriate range of the population in most periods. The population of scientific research institutions is not well adapted to the development of enterprise IP and the whole innovation ecosystem. Enterprise IP is the leading IP in the ecosystem, which is at the core of the innovation ecosystem and plays a leading role in the evolution of the innovation ecosystem. Figures can be used to make a more intuitive analysis.

Figure 2 shows that P_1, EP_1, and MP_1 share the same trend, and there is little difference between the three values. The development scale of enterprise IP conforms to the double standard set by the resource constraint model and MCGP model. Enterprises are the main body of the market economy, and the innovation activities of enterprises are more suitable for the market environment. Since 2010, the scale of enterprise IP has increased rapidly. It shows that the innovative ecological environment can promote the rapid

Table 1: Relevant data of empirical analysis.

Year	P_1	P_2	$E_{R\&D}$	P_3	$\overline{R}$	E_1	E_2	EP_1	EP_2
2017	19323	1266	2260	20589	1098	7699	753	17409	6863
2016	19186	1190	2027	20376	995	6905	676	17229	6792
2015	18872	1113	1801	19985	901	6135	600	16898	6662
2014	14150	998	1653	15148	1091	5631	551	12808	5049
2013	12283	944	1487	13227	1124	5066	496	11184	4409
2012	11133	909	1288	12042	1070	4388	429	10182	4014
2011	7712	795	1072	8507	1260	3652	357	7193	2836
2010	2257	714	858	2971	2888	2923	286	2512	990
2009	2159	713	717	2872	2497	2443	239	2428	957
2008	2508	693	797	3201	2490	2715	266	2707	1067
2007	2236	632	686	2868	2392	2337	229	2425	956
2006	1831	658	691	2489	2776	2354	230	2105	830
2005	1695	700	400	2395	1670	1363	133	2025	798
2004	1569	716	519	2285	2271	1768	173	1932	762
2003	1271	702	374	1973	1896	1274	125	1668	658
2002	1222	859	296	2081	1422	1008	99	1760	694
2001	977	744	245	1721	1426	836	82	1455	574
2000	968	816	208	1784	1166	709	69	1508	595

Table 2: Solution and scale suitability interval of MCGP model.

Year	MP_1	MP_2	EP_1	EP_2	IP_1	IP_2	ARP_1	ARP_2
2017	16263	1237	17409	6863	(16263, 17409)	(1237, 6863)	F	T
2016	15913	1201	17229	6792	(15913, 17229)	(1201, 6792)	F	F
2015	16820	1185	16898	6662	(16820, 16898)	(1185, 6662)	F	F
2014	13166	1020	12808	5049	(12808, 13166)	(1020, 5049)	F	F
2013	15673	886	11184	4409	(11184, 15673)	(886, 4409)	T	T
2012	14206	959	10182	4014	(10182, 14206)	(959, 4014)	T	F
2011	9841	855	7193	2836	(7193, 9841)	(855, 2836)	T	F
2010	2880	768	2512	990	(2512, 2880)	(768, 990)	F	F
2009	2755	744	2428	957	(2428, 2755)	(744, 957)	F	F
2008	1816	714	2707	1067	(1816, 2707)	(714, 1067)	T	F
2007	1619	680	2425	956	(1619, 2425)	(680, 956)	T	F
2006	1326	694	2105	830	(1326, 2105)	(694, 830)	T	F
2005	1227	681	2025	798	(1227, 2025)	(681, 798)	T	T
2004	1136	662	1932	762	(1136, 1932)	(662, 762)	T	T
2003	920	655	1668	658	(920, 1668)	(655, 658)	T	F
2002	885	794	1760	694	(885, 1760)	(694, 794)	T	F
2001	707	687	1455	574	(707, 1455)	(574, 687)	T	F
2000	701	754	1508	595	(701, 1508)	(595, 754)	T	F

growth of enterprise IP. The changing trend of the MP_1 variable in 2013 and 2014 is different from that of the other two variables. The main reason is that there are differences in the sensitivity of enterprise innovation population and scientific research institution innovation population to resources. In practice, it can be understood that enterprises are more sensitive to the market environment and their innovation activities are more flexible. Innovation population in 2010 saw a rapid growth rate much higher than the previous growth rate and then maintained a different growth pattern from that before 2010. The main reason for this phenomenon is that the positive impact of innovation investment and industrial policy has increased significantly since 2010.

Figure 3 shows that P_2 and MP_2 share the same trend. There is little difference between the two values. After 2010, EP_2 is different from P_2 and MP_2. The development scale of IP in scientific research institutions is in line with the standard set by the MCGP model. EP_2 has a more similar trend line to P_1 and EP_1. This is the requirement of the coordinated development of heterogeneous populations. However, scientific research institutions cannot adapt to the market environment like enterprises. P_2 does not make full use of innovative resources to make the population develop faster. This also limits the further development of synergy between P_1 and P_2.

2.5. Synergy Evaluation. This paper evaluates the synergy relation with entropy evaluation. Entropy value is always used to measure the chaos in a system. The system is more chaotic while the entropy is larger. When the entropy is smaller, the cooperation will be better [21, 22]. Let $\langle U, \pi \rangle$ be

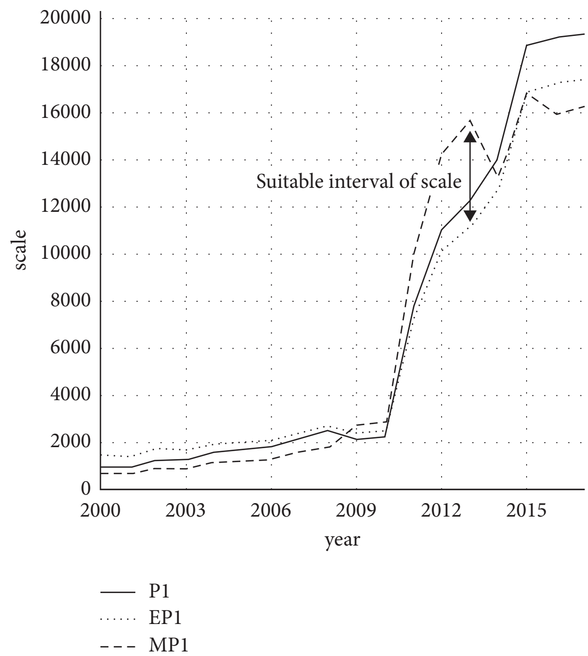

Figure 2: Trend comparison of P_1, EP_1, and MP_1.

an approximation space, where partition π consists of blocks U_i, $1 \le i \le k$, each of which has cardinality n_i. The information entropy $H(\pi)$ of partition π is is defined as [23, 24]

$$H(\pi) = -\sum_{i=1}^{k} \frac{n_i}{n} \log \frac{n_i}{n}, \quad n = \sum_{i=1}^{k} n_i. \tag{19}$$

This paper divides entropy into full collaborative entropy and nonfull collaborative entropy. The optimal data entropy of the MCGP model (MP) is full collaborative entropy. The equilibrium solution (EP) and sample data (P) are nonfull collaborative entropy. The nonfull synergy entropy and full synergy entropy are defined as [16]

$$\begin{aligned} H_f(\pi) &= -\sum_{i=1}^{k} \frac{n_i}{n} \log \frac{n_i}{n}, \quad n = \sum_{i=1}^{k} n_i, \\ H_{\mathrm{nf}}(\pi) &= -\sum_{i=1}^{k} \frac{n_i}{n} \log \frac{n_i}{n}, \quad n = \sum_{i=1}^{k} n_i. \end{aligned} \tag{20}$$

This paper gives the definition of collaborative efficiency (R_C):

$$R_C = 1 - \frac{H_f(\pi)}{H_f(\pi) + H_{\mathrm{nf}}(\pi)}. \tag{21}$$

The full collaborative entropy, nonfull collaborative entropy, and collaborative efficiency of P, EP, and MP are shown in Table 3.

As shown in Table 3, the mean R_C of P, EP, and MP is 0.165, 0.205, and 0.831. The collaborative efficiency of sample observations is the lowest. The collaborative efficiency of the MCGP model is higher than the collaborative efficiency of the sample observations and equilibrium solution. It can be seen that the system after model optimization has better performance in synergy. This shows that the optimization model in this paper is conducive to the determination of the collaborative scale of the innovation population. The method proposed in this paper is effective.

3. Results and Discussion

In this study, the interaction model of IPs is constructed from the perspective of a combination of ecological theory and innovation theory. When the scale suitability of IP in a region is evaluated, it is not comprehensive only from the perspective of resource constraints or output maximization. The resource constraint model based on logistic regression and the multichoice goal programming model are combined to build an analysis path that takes both input and output perspectives into account. At the same time, using the interval value to evaluate suitability makes the population scale suitability evaluation more operable. The results of empirical analysis in Jiangsu Province show that the combination of resource constraint model and multichoice goal programming model can better evaluate the scale suitability of IPs such as enterprises and scientific research institutions in a region. According to the evaluation results, local governments can modify the relevant innovation policies to promote the self-organization evolution of IP.

Interaction relationship within enterprise population is a common topic in the innovation system [25, 26]. Related researches are held from two perspectives of resource constraints [27] and organizational ecology [28]. It is popular to use the MCGP model to analyze the competition of the innovation population [16, 29]. In this paper, population dynamics and MCGP are combined to construct a multichoice model. Based on the optimization results, the

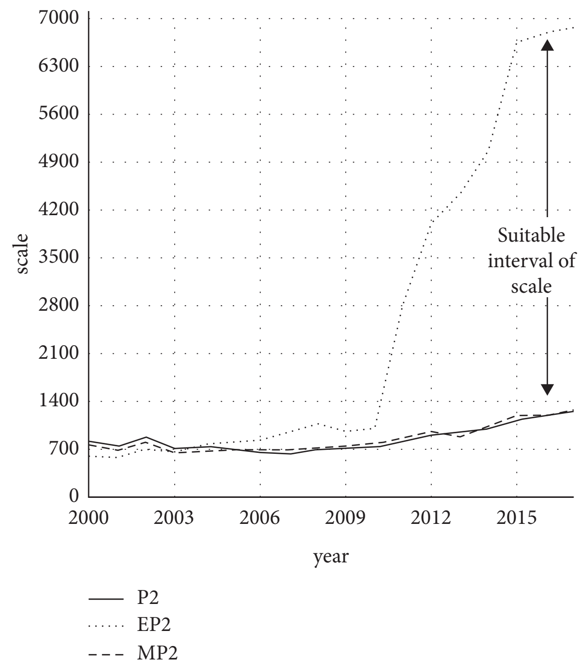

Figure 3: Trend comparison of P_2, EP_2, and MP_2.

Table 3: $H_f(\pi)$, $H_{nf}(\pi)$, and R_C of P, EP, and MP.

Year	P			EP			MP		
	H_f	H_{nf}	R_C	H_f	H_{nf}	R_C	H_f	H_{nf}	R_C
2017	1.000	0.100	0.091	1.000	0.259	0.205	0.111	1.000	0.900
2016	1.000	0.097	0.088	1.000	0.259	0.205	0.110	1.000	0.901
2015	1.000	0.093	0.085	1.000	0.259	0.205	0.105	1.000	0.905
2014	1.000	0.105	0.095	1.000	0.259	0.205	0.112	1.000	0.899
2013	1.000	0.112	0.100	1.000	0.259	0.205	0.091	1.000	0.917
2012	1.000	0.116	0.104	1.000	0.259	0.205	0.102	1.000	0.907
2011	1.000	0.135	0.119	1.000	0.259	0.205	0.121	1.000	0.892
2010	1.000	0.239	0.193	1.000	0.259	0.205	0.224	1.000	0.817
2009	1.000	0.243	0.196	1.000	0.259	0.205	0.225	1.000	0.817
2008	1.000	0.227	0.185	1.000	0.259	0.205	0.258	1.000	0.795
2007	1.000	0.229	0.186	1.000	0.259	0.205	0.264	1.000	0.791
2006	1.000	0.251	0.201	1.000	0.259	0.206	0.279	1.000	0.782
2005	1.000	0.262	0.208	1.000	0.259	0.205	0.283	1.000	0.779
2004	1.000	0.270	0.213	1.000	0.259	0.206	0.286	1.000	0.778
2003	1.000	0.283	0.220	1.000	0.259	0.206	0.295	1.000	0.772
2002	1.000	0.294	0.227	1.000	0.259	0.206	0.300	1.000	0.769
2001	1.000	0.297	0.229	1.000	0.259	0.206	0.301	1.000	0.769
2000	1.000	0.299	0.230	1.000	0.259	0.206	0.301	1.000	0.769
Mean	1.000	0.203	0.165	1.000	0.259	0.205	0.209	1.000	0.831

population collaborative evaluation is carried out. This method integrates and expands the application fields of the two models, and it is applicable for practical issues.

4. Conclusion

The research objective of this paper is to explore a method that can accurately determine the appropriate scale of innovation population development. In order to achieve this goal, this study constructs a dynamic model of the growth of innovative population based on resource constraints model and estimates the suitability of population size with the help of multichoice goal programming method. Two proposed models are constructed to obtain the appropriate population-scale interval. The results show that the research goal of this paper has been well realized.

The theoretical contribution of this paper is that it constructs the theoretical model from two aspects of input constraint and output maximization. The practical significance of the research lies in that it can provide an appropriate analysis method for various innovation subjects and government agencies to analyze and plan the development of IP.

The innovation subject should approach the innovation activity with the ecosystem view in the management practice. When making public policies, the government should face up to the objective law of innovation and development. The government should not blindly encourage the scale expansion of enterprises and scientific research institutions; instead, the government should pay attention to the development structure of IP, which easily restricts the input-output efficiency of the innovation ecosystem, instead of the scale of IP. Governments at all levels can draw on the ideas of this study and formulate relevant policies to guide the appropriate development of the IP scale. Enterprises and scientific research institutions and other innovative subjects can use the research method of this paper to analyze the innovation competition situation of different industries. Enterprises and scientific research institutions can adjust innovation development strategy and innovation resource allocation based on the results of competitive situation analysis. In this study, the different life cycles of IP development are not considered, and future studies could consider the characteristics of population life cycle development.

Data Availability

The data used to support the findings of the study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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